OBSERVATIONS ON CHROME MAGNET STEEL

BY

R. A. WIGHT

ARMOUR INSTITUTE OF TECHNOLOGY

1918

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Observations on chrome
 magnet steel

OBSERVATIONS

ON

THE RELATION BETWEEN THE CHROMIUM CONTENT AND THE HARDENING TEMPERATURE OF CHROME MAGNET STEEL

A THESIS

PRESENTED BY

ROBERT A. WIGHT

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

CHEMICAL ENGINEER

IN

CHEMICAL ENGINEERING

MAY 29, 1918

APPROVED:

Professor of Chemical Engineering

H M Raymond
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L. C. Monin
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The production of magnetos and of many other kinds of electrical apparatus is dependent to a large extent upon the supply of steel suitable for permanent magnets of good quality. There are several kinds of magnet steel but for magnets which must possesss high flux, together with high retentivity only tungsten steel is usually considered. This is a high grade steel containing usually about .60% of carbon and 5.00% of tungsten.

After the outbreak of the European war most of the small amount of tungsten available was used for the manufacture of the high-priced high-speed tool steels and tungsten magnet steel became very expensive and hardly obtainable at any price. This necessitated the production of some steel which could be used as a substitute. Several of these have been developed by different manufacturers, most of them being chrome steels.

One difficulty in the use of all magnet steels is that the composition of the steel is

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only one of many factors affecting the magnetic qualities. Even when the hardening temperatures and method of handling are the same two steels of practically identicalcomposition are liable to have widely varying magnetic properties. Apparently the whole previous history both physical and thermal has a decided influence on the results obtainable. For this reason it is necessary to determine by actual test the temperature at which each lot of steel must be hardened to give satisfactory results. When the flux desired is such as to be nearly the maximum possible for the grade and section of steel used, extensive tests are often necessary to determine the proper hardening temperature.

It occurred to the writer that by a slightly more extended study of some of the chrome magnet steels which are being substituted for tungsten magnet steel a relation might befound between the chromium content and the proper hardening temperature. At the same time it was desired to ascertain whether a chrome steel which did not give good results when hardened at the usual temperatures could be used by

hardening at a considerably higher heat. In the case of tungsten magnet steels it has been found that a steel which gives only mediocre flux when hardened at approximately 1600°F. and still less at 50-100° higher is often entirely satisfactory when hardened at 1800° or more.

Five chrome magnet steels varying in chromium content were therefore made up into magnets of the form in which they were used and hardened at different temperatures. These magnets were then magnetized by a strong electro-magnet and placed in trays with like poles adjacent and at a distance of one inch apart. They were aged for twenty-four hours and the magnetic flux in maxwells read on the Grassot fluxmetre. They were then remagnetized, aged twenty-four hours, and again tested. The composition of these steels was as follows:

	Silicon	Sulphur	Phosphorus	Manganese	Carbon	Chromium	Nickel
#1-	---	.034	.030	.41	.50	1.03	---
#2-	.17	.027	.018	1.23	.80	1.64	
#3-	.19	.032	.030	.53	.73	1.97	
#5-	.23	.019	.015	1.37	.81	2.23	
#6-	.25	.028	.018	.73	.91	2.35	.06

The numbers refer to the number of the drawing contain-

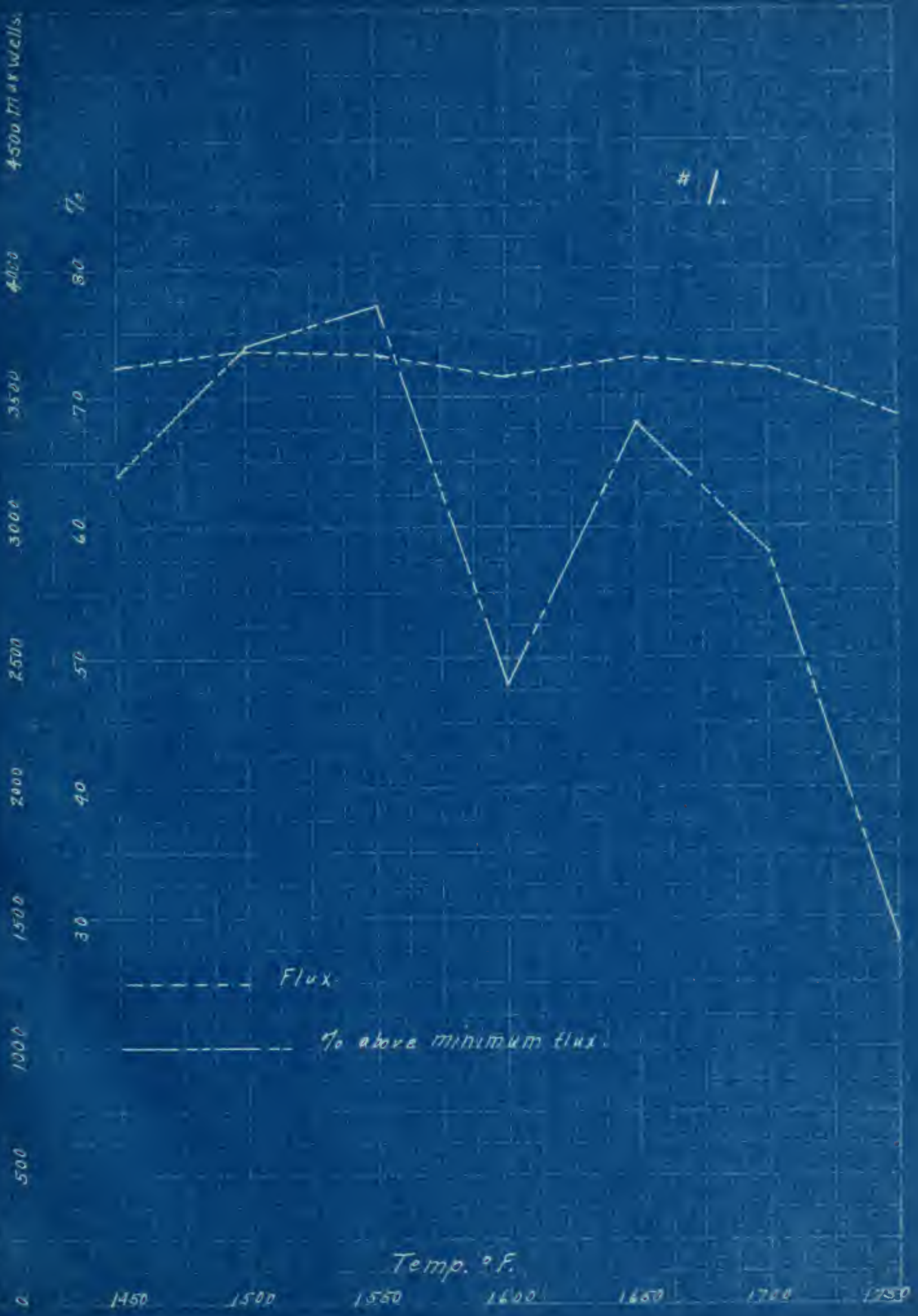
ing the diagram of flux variation with variations in hardening temperature.

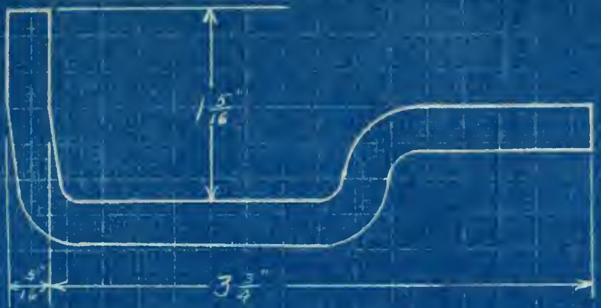
These steels were hardened in a gas fired muffle furnace equipped with pyrometer, and with a tank of cold running water immediately in front of the furnace. The forming of the magnets into shape was done with a drop hammer with the steel at a red heat.

Steel #1 was 5/16" x 1 1/4" in cross-section. It was formed into magnets of shape #1 drawing #8, hardened and magnetized and tested. This lot of steel was not a good sample of the steels of its grade. This is best shown by the percentage passing the minimum flux requirement of 3600 maxwells.

Temperature	1450	1500	1550	1600	1650	1700	1750
Flux	4200	4000	3900	3900	3900	3900	3500
	3400	3500	3600	3900	3300	4000	3300
	3700	4000	3700	3700	3900	3800	3100
	3400	3600	3700	3800	3300	3600	3300
	3600	4000	3700	3800	4100	3700	3600
	3500	3700	3600	4000	3200	3500	3600
	3600	3800	3600	3400	3900	3700	3500
	3600	3600	3500	3700	3900	3700	3300
	3400	3800	3600	3500	3600	3800	3600

#1.


4500 maxwells.
4000
3500
3000
2500
2000
1500
1000
500
0
%
80
70
60
50
40
30
Flux.
% above minimum flux.
Temp. °F.
1450
1500
1550
1600
1650
1700
1750



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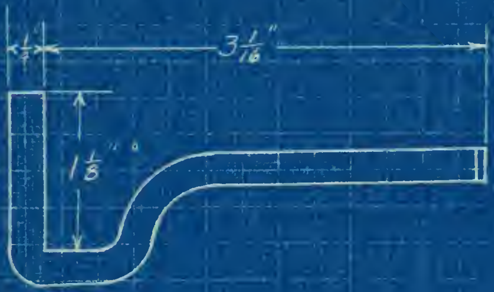

2.

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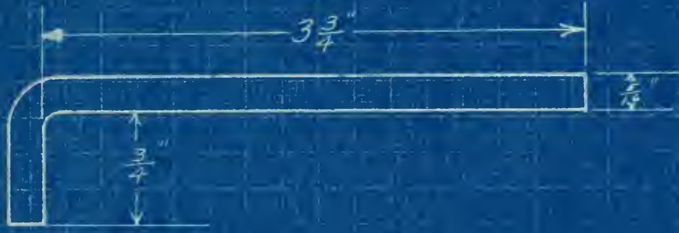

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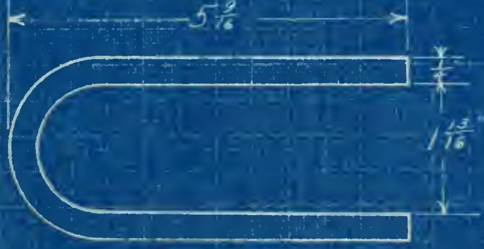


4.

Temperature	145o	1500	1550	1600	1650	1700	1750
Flux	3800	3700	4000	3800	3700	3700	3800
	3500	3600	3900	3200	3800	3700	3500
	3800	3700	3700	3500	3700	3600	3600
	3600	3600	4000	3300	3800	3500	3200
	3700	3500	3600	3700	3500	3400	3600
	3400	4000	3600	3400	3900	3600	3100
	3600	3800	3800	3200	3600	3500	3400
	3700	3300	4200	3200	3700	3600	3400
	3600	3500	3400	3400	3600	3400	3200
	3800	3600	3400	3800	3500	3500	3600
	3600	3700	3500	3900	3800	3700	3100
	3600	3500	3400	3500	3300	3500	3400
	3900	3700	3600	3600	3300	3500	3500
	3400	3400	3600	3200	3500	3300	3500
	3400		3700	3500	3600	3500	3400
	3500		3400	3500	3600	3500	3400
			3600			3800	
Average	3612	3678	3661	3676	3640	3615	3420
% Good	64	74	77	50	68	58	28

Steel #2, 1.65% Chromium was 1/4" x 3/4" in cross-section, and was formed according to shape #2

#2.

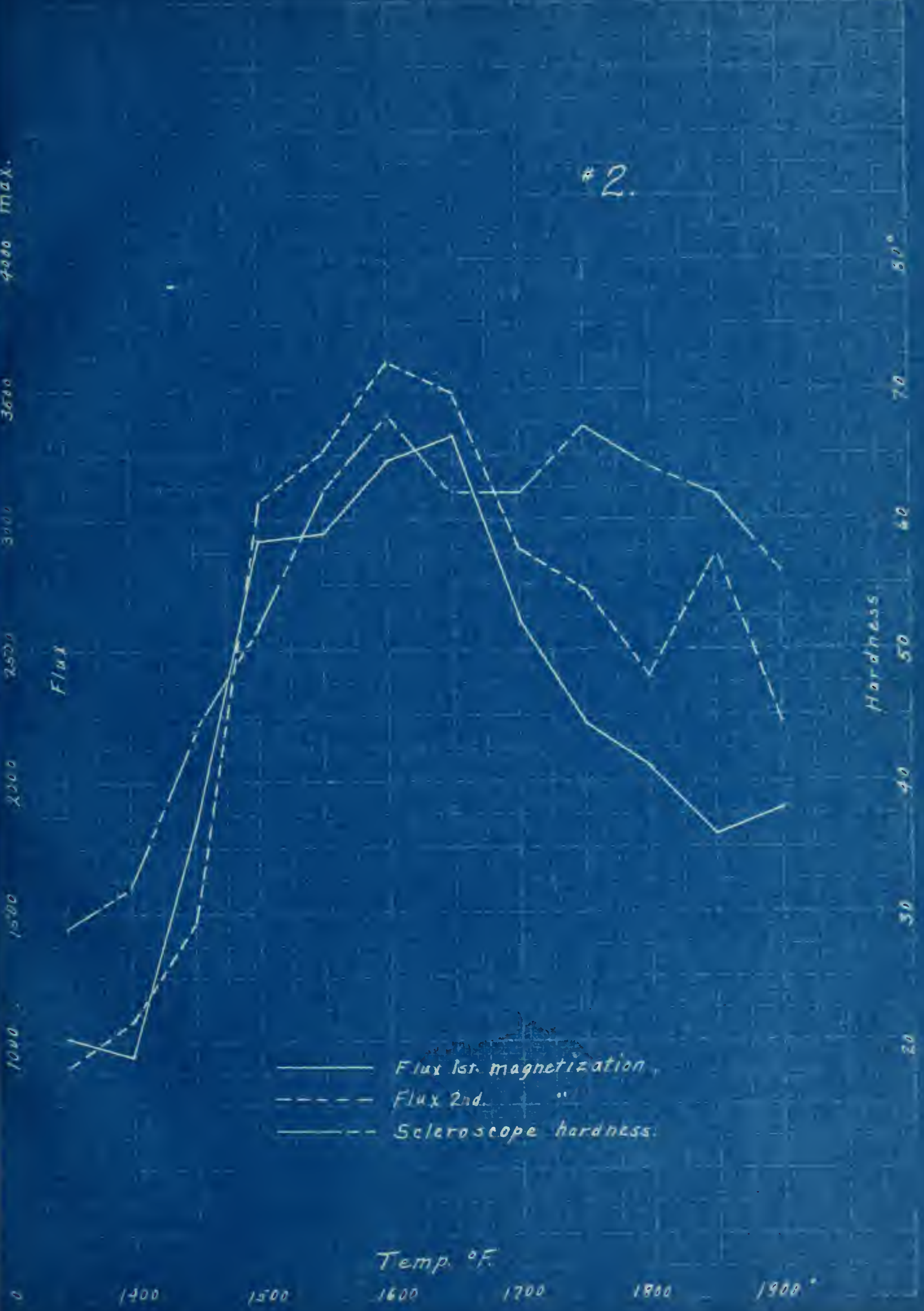

4000 max.
3500
3000
2500
2000
1500
1000
Flux
80°
70
60
50
40
30
20
Hardness
Flux 1st. magnetization.
Flux 2nd. "
Scleroscope hardness.
Temp. °F.
0
1400
1500
1600
1700
1800
1900°

figure #8. The results were as follows:

1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900°F
1100	900	1100	3200	2900	3100	3300	2800	2300	2300	2200	2100
800	1000	3000	2700	3000	3200	3300	2700	2200	2000	2000	1900
1200	700	1100	2700	3000	3200	3300	2300	1900	2100	1800	2100
1200	1000	1100	2900	3000	3300	3200	2400	1900	1900	1700	1800
1100	1100	3200	2800	3000	3200	3100	3100	2100	2200	1800	1700
900	800	2900	3100	2900	3100	3200	2500	2400	1800	1900	1700
1000	1000	1200	2900	2900	3000	3500	2400	2300	2300	1900	1800
900	700	2000	3000	2700	3500	3300	2800	2300	1800	1900	2000
1000	1100	2000	2900	3000	3500	3300	2900	2500	1900	2000	1900
900	1100	1000	3000	3000	3100	3800	3000	2300	2200	1800	2000

Averages.

1010	940	1860	2920	2940	3220	3330	2690	2220	2050	1800	1900

These magnets were then re-magnetized, aged twenty-four hours, and tested as before:

1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900°F
700	1000	700	3500	3600	3400	3500	2700	2900	2400	2900	2600
900	1300	800	3200	3200	3300	3400	2900	2700	2300	2800	2100
1000	1200	1200	3100	3000	3700	3700	2700	2700	2200	3000	2200
800	900	2200	2900	3100	3500	3300	2900	2700	2500	2800	2300
1100	1100	800	3200	3400	3600	3400	3000	2500	2600	2900	2100

1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900°F
1100	800	2800	3000	3000	3700	3500	3300	2900	2300	2700	2000
700	1100	1000	2800	3400	3500	3600	2700	2800	2200	2900	2300
700	1100	2700	2800	3300	3700	3400	2900	2900	2400	3000	2100
1100	1200	700	3100	3200	3800	3300	2900	2700	2600	2800	2200
800	1100	1800	3200	3400	3800	3800	2800	2500	2400	2900	2300

Averages.

890	1080	1470	3080	3260	3600	3490	2880	2730	2390	2870	2220
											max.

The scleroscope hardness, universal hammer, was as follows:

30	32	30	57	60	73	60	60	64	65	65	55
28	32	58	50	63	62	62	62	68	65	60	55
28	31	57	50	63			62		63		

Averages.

29	32	44	52	62	68	62	62	67	64	62	55

It will be noted that the maximum flux on first magnetization was obtained at a temperature of 1650°, while 1600 gave the maximum on re-magnetization. Brinnell tests could not be taken effectively as the steel was too hard. The magnets were therefore cleaned with fairly coarse emery cloth and the scleroscope hardness obtained using the universal hammer.

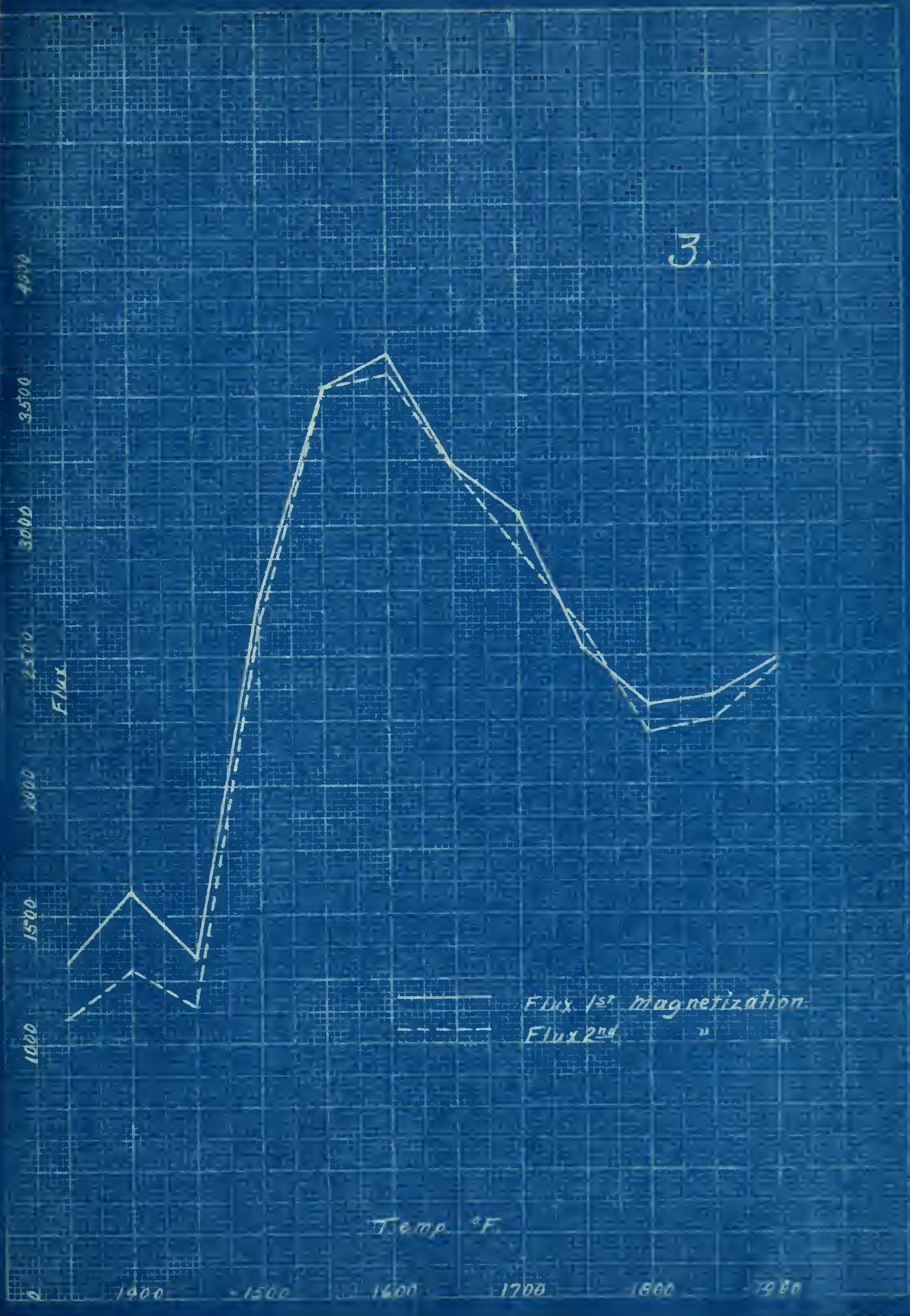
The results were fairly

consistent, the average reading being recorded for each magnet tested. The temperature of maximum hardness will be noticed to coincide with that of maximum flux on second magnetization. The number of hardness tests made was not sufficient to enable me to state definitely that the dip in the hardness curve was not due partly to experimental errors, the surface of a number of the magnets being irregular from the forging. This affects the scleroscope readings materially.

Steel #3, 1.97% Chromium was also 1/4" x 3/4" in section and was formed into shape #2. The results on hardening were as follows, the flux obtained being tabulated under the hardening temperature corresponding:

1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900°F
1500	1700	1500	2900	3200	3600	3300	2700	2700	2400	2500	2100
1300	1400	1400	2300	3400	3700	3400	3100	2500	2200	2300	2500
1500	1600	1300	1000	3500	3700	3300	2800	2500	2500	2400	2500
1200	1600	1500	3100	3400	3600	3300	3200	2600	2500	2300	2000
1000	1700	1400	2600	3400	3400	3100	3300	2400	1900	2300	3500
1500	1500	1400	2300	3800	3500	3000	3000	2400	2300	2200	2500
1100	1700	1200	2800	3900	3600	3100	2700	2500	2500	2500	2600

3.



Flux
4000
3500
3000
2500
2000
1500
1000
0
Temp. °F.
1400
1500
1600
1700
1800
1900
Flux 1st magnetization
Flux 2nd "

1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900°F
1300	1600	1400	3200	3600	3700	3200	3100	2500	2300	2400	2400
1300	1500	1100	2400	3700	4000	3100	3200	2500	2300	2500	2400
1400	1600	1200	3000	3400	3800	3500	3400	2600	2200	2100	2400

Averages.

1310	1590	1340	2733	3530	3660	3230	3050	2520	2310	2350	2490

These magnets were then re-magnetized, aged twenty-four hours, and tested as before.

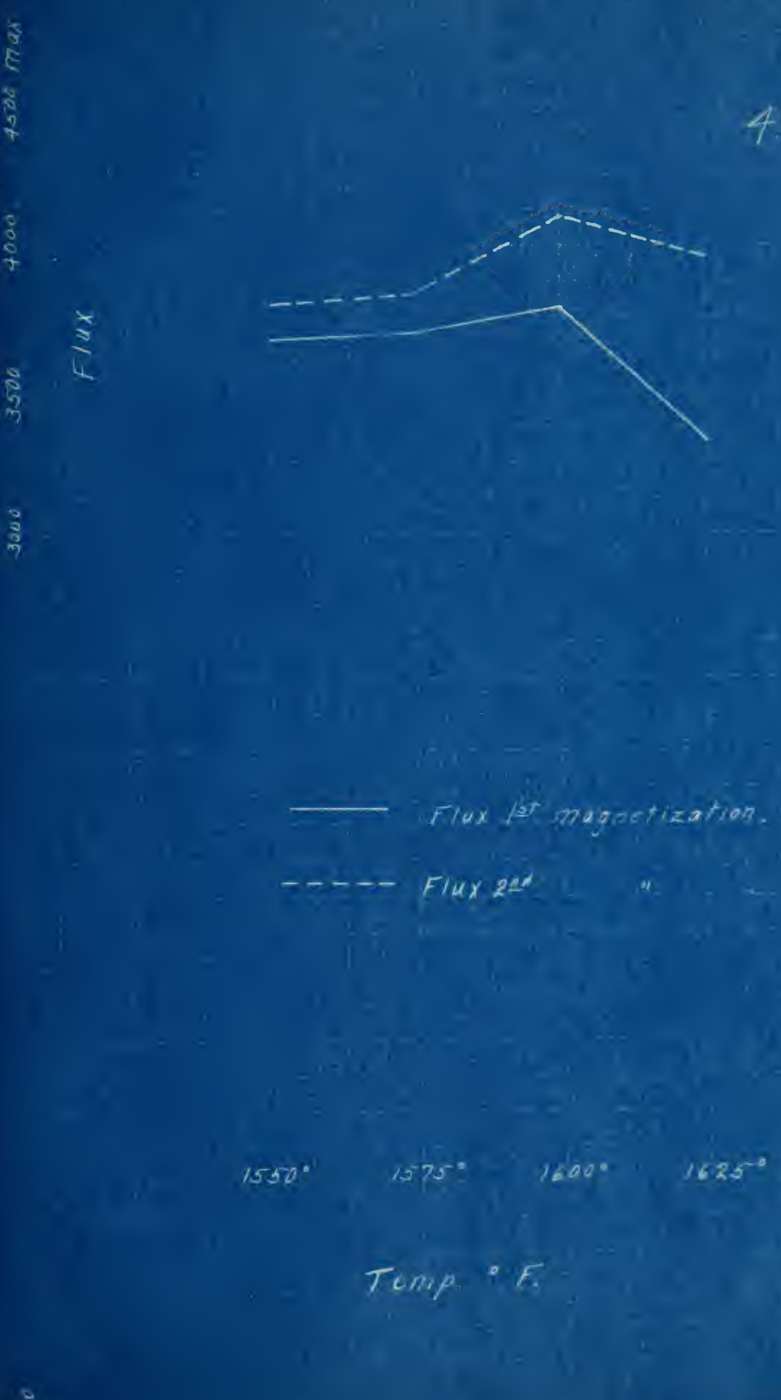
1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900°F
1000	1400	1400	700	3500	3700	3400	3200	2900	2400	2600	2500
900	1300	1200	3000	3700	3700	3400	3400	2600	1900	2200	2500
1400	1400	1300	3000	3300	3400	3000	2900	2700	2000	2300	2500
1000	1300	1200	3300	3600	3500	3100	2900	2900	2400	2100	2600
1200	1000	1300	2400	3700	4100	3000	2400	2700	2200	2100	3600
1200	1100	1000	2400	3200	3600	3200	3100	2600	2300	2000	2100
1400	1400	900	2700	3700	3300	3300	2900	2200	2000	2600	2400
1000	1400	1300	2600	3300	3500	3200	3000	2500	2400	2100	2100
1100	1300	1400	2400	3600	3500	3200	2400	2500	2500	2500	2000
800	1300	500	2100	3700	3500	3400	2900	2400	2000	2000	2300

Averages.

1100	1290	1150	2655	3520	3580	3220	2910	2600	2210	2250	2460

The flux obtained with this steel was somewhat

4


4500 max
4000
3500
3000
0
Flux
Flux 1st magnetization.
Flux 2nd "
1550°
1575°
1600°
1625°
Temp. ° F.

greater than with steel #2. The range of effective temperature was also slightly greater. Re-magnetization did not raise the flux in this case but lowered it slightly. The maximum flux occurred in each case at a hardening temperature of 1600° F.

Steel #4 was of the same composition as #3 but was of 5/16" x 1-1/4" section. It was tested at temperatures close to the proper temperature for #3, and also showed 1600° F. as the best temperature. The magnet was formed according to #3 figure #8.

Temperature	1550	1575	1600	1625° F.
Flux	3400	3700	4000	3300
	3700	3800	3900	3300
	3700	3600	3600	3300
	3900	3700	3600	3400
Average	3675	3700	3775	3325

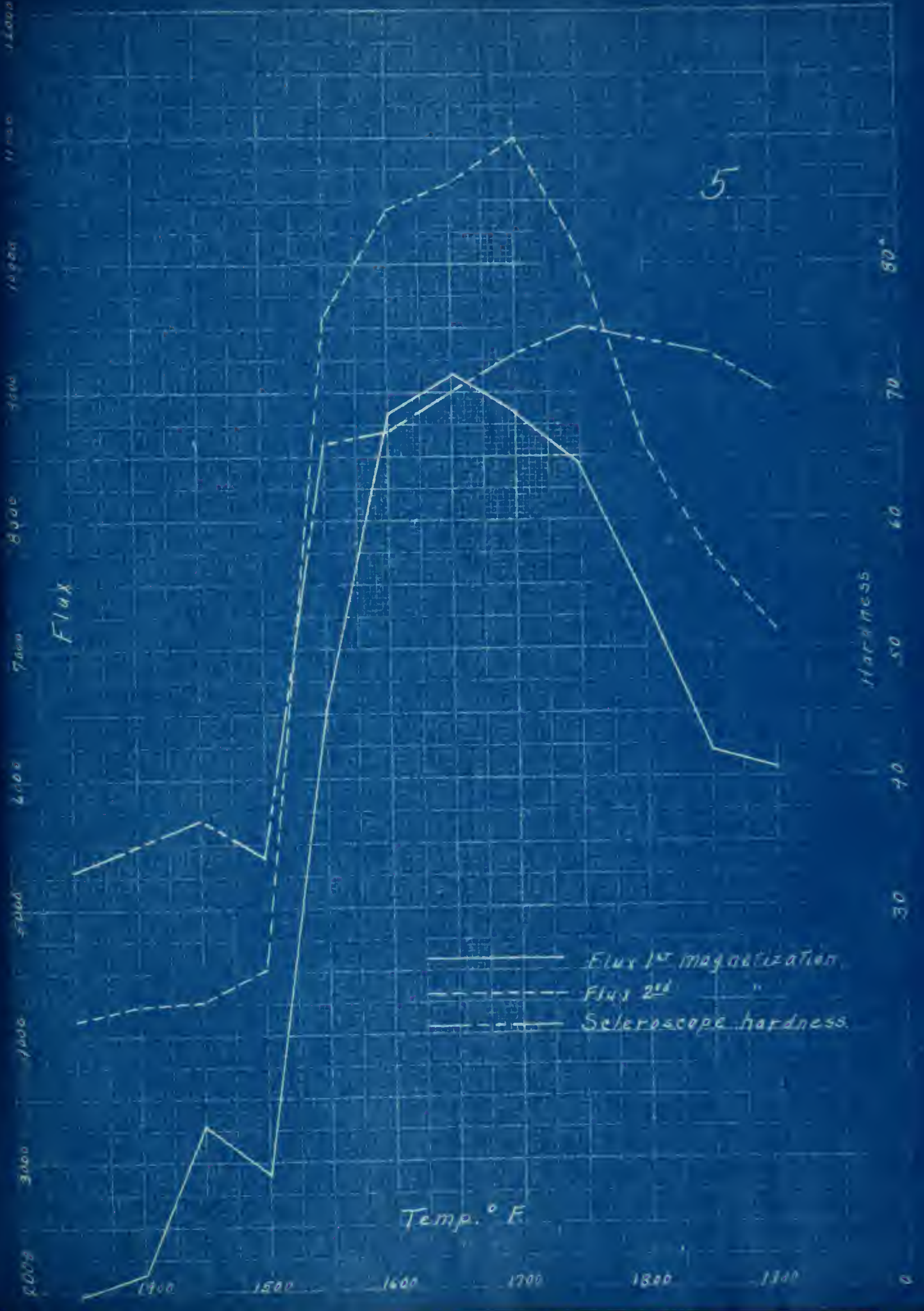
The results on re-magnetization were as follows:

Temperature	1550	1575	1600	1625° F.
Flux	3950	4000	4100	4000
	3900	3800	4000	3900
	3700	3950	4000	3900
	3650	3600	4300	4100

Average 3800 3837 4100 3975

Steel #5, 2.25% Chromium, was of 1/4" x 31/32" section. It was formed according to shape #4 figure #8. These magnets were heated in a gas fired furnace equipped with a mechanical feed for forcing the magnets through the furnace. On reaching constant temperature they are formed to exact shape in a pair of specially designed tongs and are held in these tongs during quenching. When, as sometimes happens, there is trouble in getting the tongs adjusted, then the steel cools considerably in this time between withdrawal from the furnace and quenching, giving erratic results. Several flux readings were discarded out of this set on this account. For convenience in tabulating I have put the flux down as 1/100 of the actual flux in maxwells.

1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900°F
42	10	39	21	19	100	70	79	66	74	56	57
6	35	33	24	100	85	104	97	89	78	54	59
12	41	30	33	96	83	73	89	88	70	75	66
7	26	37	23	56	86	110	80	82	66	55	68
33	34	26	44			100	92	88	79	61	59


5
Flux
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
Hardness
80°
70
60
50
40
30
0
Temp. ° F.
1400
1500
1600
1700
1800
1900
Flux 1st magnetization
Flux 2nd "
Scleroscope hardness.

1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900°F
27	15						93	94		70	54
32	11										
1988	2150	3300	2900	6525	8850	9140	6833	8450	7340	6183	6050 max.

These magnets were re-magnetized, aged twenty-four hours, and tested again.

1350	1400	1450	1500	1550	1600	1650	1700	1750	1800	1850	1900°F
45	38	42	63	87	93	79	112	104	86	79	73
30	50	40	360	116	111	119	104	107	82	65	73
32	33	35	43	112	95	96	110	98	83	71	66
46	43	44	52	62	110	118	107	107	87	78	81
45	41	41	34	102	102	120	109	104	89	83	76
50	46	44					118	88		87	78
44	44	52									
43	44										
36	42										
4122	4233	4257	4520	9580	10420	10640	11000	10133	8540	7717	7117 max.

Scleroscope, universal hammer.

34	35	34	34	74	65	73	74	76	74	75	67
33	35	35	36	76	65	70	72	77	75	76	65

30	35	38	33	60	65	70	74	74	73	71	74
27	34	40	34	43	70	70	74	73	73	72	72
37				72							67
38				72							65
33	35	37	34	66	67	70	73	75	74	73	70

This steel differed from the previous lots in that no two maxima occurred at the same temperature. The maximum flux on first magnetization occurred at a hardening temperature of 1650, while the maximum on re-magnetization occurred at 1700, and the maximum hardness at 1750° F.

Steel #6, 2.35% Chromium, was also of 1/4" x 3/32" section, and was formed per #4. Fifty magnets were hardened at each temperature using the same procedure as with #5.

	1500	1525	1550	1575	1600	1625° F.
Max.	9700	10100	10200	10200	9500	9800
Min.	6400	4400	7200	7200	6800	7700
Ave.	7880	7604	7941	8296	8170	8650
	Remagnetized and aged.					
Max.	10400	9900	9700	10200	9900	9900
Min.	7200	4900	6800	7100	8000	8300
Ave.	8508	7432	8320	8541	8954	9004

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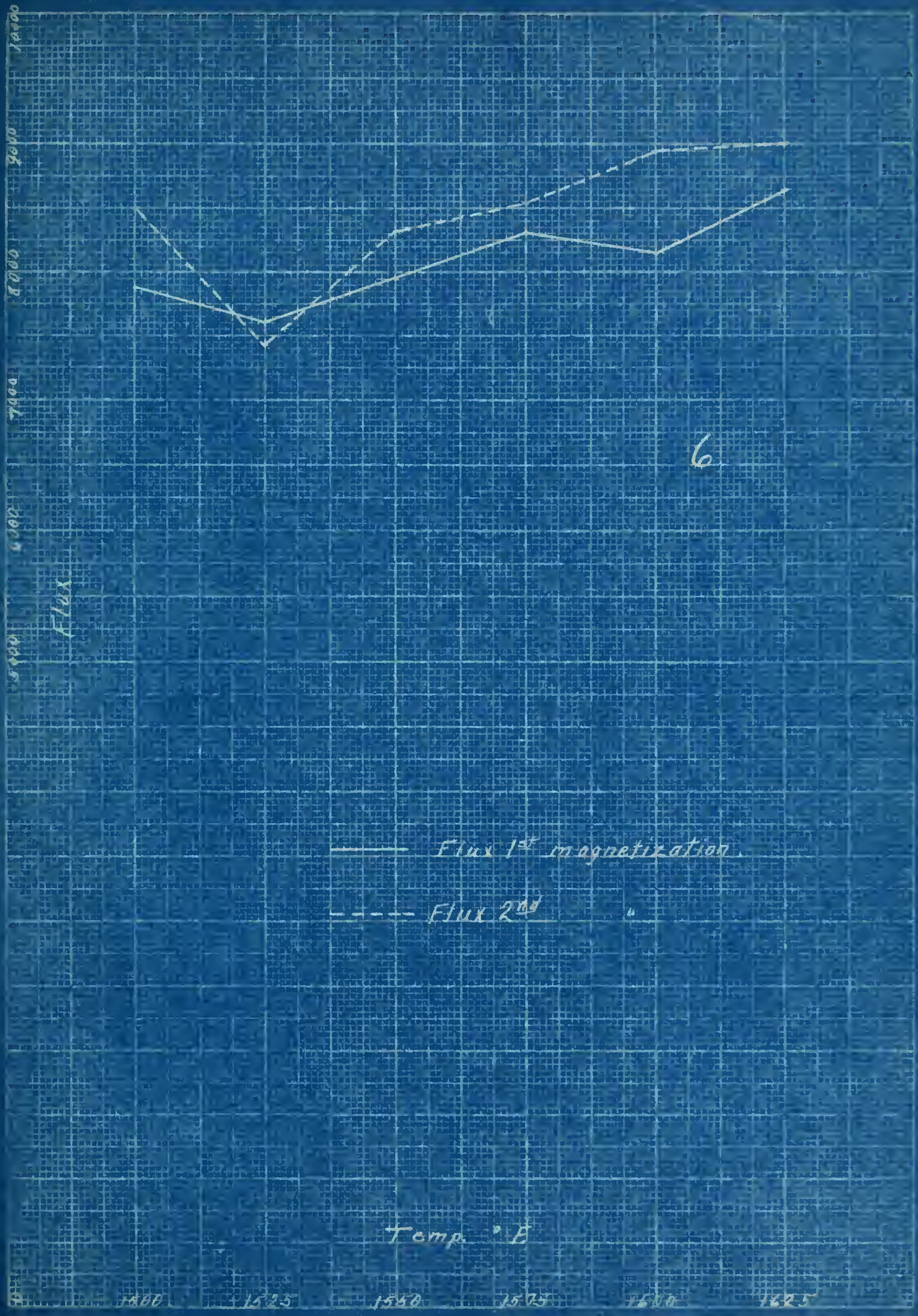
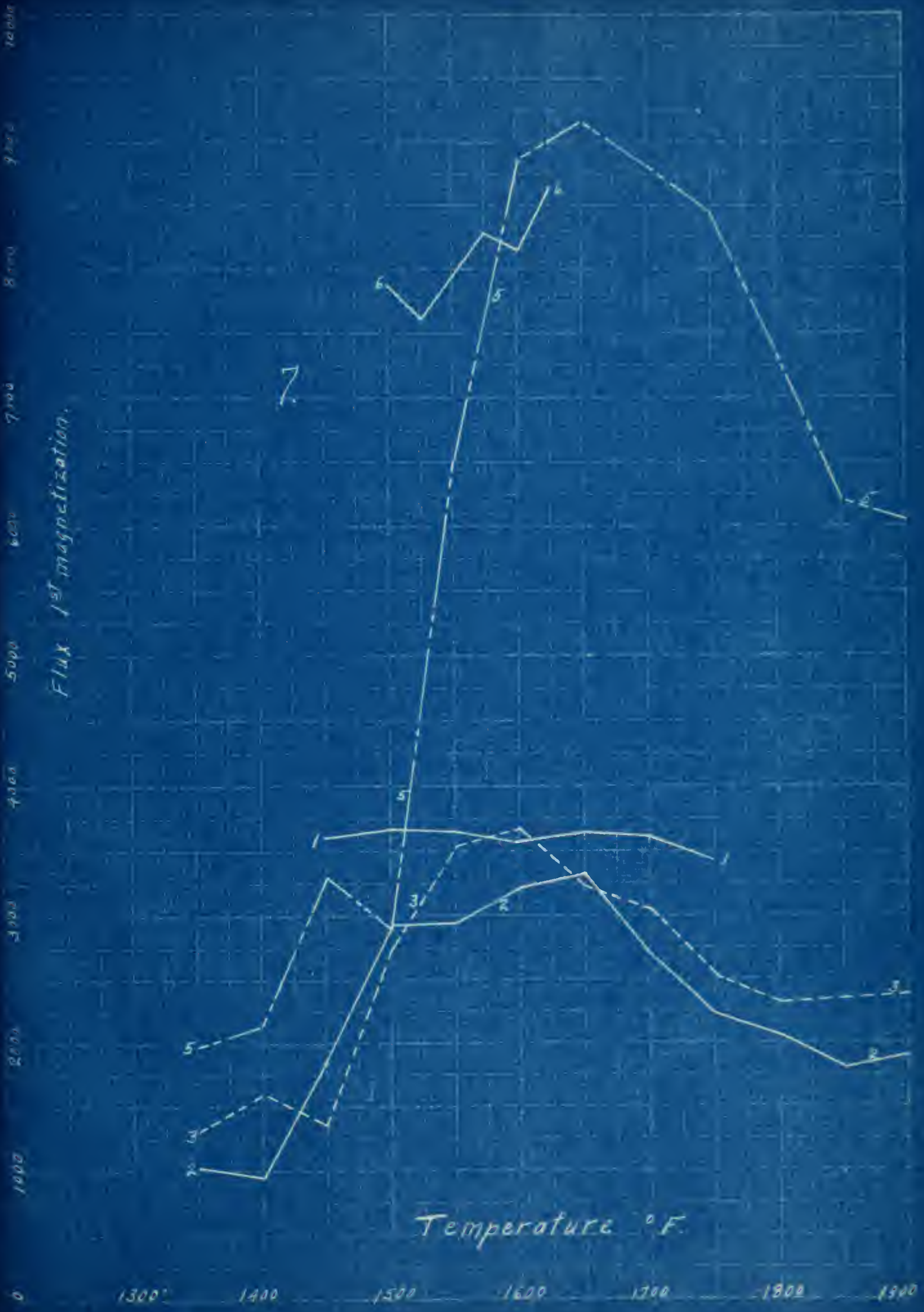

10000
9000
8000
7000
6000
5000
Flux
6
Flux 1st magnetization
Flux 2nd "
Temp °F
1500
1525
1550
1575
1600
1625


7.
Flux 1st magnetization.
Temperature °F.
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
1300°
1400
1500
1600
1700
1800
1900
1
2
3
5
6

This steel was of the same make and grade as #5 but did not give as good results. While it will be observed that the maximum of the flux variation curve had not been reached at the temperatures used a higher heat was not tried because of the high breakage, amounting to 45% at 1625°. The magnets were much more brittle than the similar magnets of lot #5.

Figure #7 was plotted to give a comparative view of the flux temperature curves for all these steels. Number four was not included as it was very similar to number three and the tests on it had not been extensive. On account of the fact that the flux requirements of the different shapes are widely different a compilation of the results was attempted, in the hope that it would show up the difference more clearly.

Steel	Flux req.	Range of Temp.	Temp. max. flux	% Cr.	% Cr+ Mn +C.
1	3600	1450-1705	1500	1.03	1.94
2	2800	1495-1690	1650	1.64	3.67
3	2800	1505-1725	1600	1.97	3.23

Steel	Flux Req.	Range of temp.	Temp. max.flux	% Cr.	% Cr+ Mn +C.
4	3600	-1610	1600	1.97	3.23
5	8500	1595-1745	1650	2.25	4.41
6	8500	1620-	+1625	2.35	3.99

On examining the curves it will be noted that while the flux curves rise again after dropping on heating beyond a certain temperature they start their rise at temperatures nearly the maximum available in this investigation. Thus while the curve is similar in general to that of tungsten steels it is apparently transposed to the higher temperature side, necessitating extreme temperatures to reach the second zone of satisfactory flux. As the fractures of magnets hardened at 1900° showed very coarse grain it is probable that magnets so hardened would be too brittle to be of much use.

In view of the many factors which influence the hardening temperature of magnet steels no definite formula for the proper temperature for any similar steel can be said to have been deduced. Some general conclusions seem to be warranted.

With two chrome magnet steels of practically identical composition otherwise the one of higher chrome content will have the higher hardening temperature and the range of temperatures at which the steel may be hardened will be narrower. This disadvantage is counter-balanced by the fact that the higher chrome magnet steels are also of higher magnetic strength.

This rise of what may be called the initial hardening temperature of the series of steels is more regular if instead of the chrome content alone we consider the sum of the percentages of chromium, carbon and manganese. The same holds true of the decrease in the effective temperature range. It seems probable that by comparing the hardening temperature determined by trial with the combined percentage of these elements on a large number of steels a curve might be plotted which would serve as a guide to the temperature limits within which the proper hardening temperature of any similar steel would be found. This should reduce the trouble of locating this desired temper-

ature. Some data have been collected for such a curve but not enough to warrant its conclusion at present.

Respectfully submitted,

Robert A. Wight
per B. B. Wight